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# Condylectomy Induced Bone Changes in the Macaca Rhesus Monkey

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CONDYLECTOMY INDUCED BONE CHANGES  
IN THE MACACA RHESUS MONKEY

by

Dean F. Skuble, D.D.S.

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A Thesis Submitted to the Faculty of the Graduate School  
of Loyola University in Partial Fulfillment of  
the Requirements for the Degree of  
Master of Science

9 June 68

DEDICATION

TO MY PARENTS FOR THEIR CONTINUAL  
SUPPORT IN THE ENDEAVORMENT OF MY  
EDUCATION.

## LIFE

Dr. Dean F. Skuble was born on May 5, 1942 in Chicago. He attended Saint Blase Parochial School in Summit, Illinois, from which he graduated in 1956. After four years at Saint Procopius Academy in Lisle, Illinois he was graduated in 1960. His pre-dental education began with a year and a half of study at Loyola University, Chicago and was completed at the University Extension in Rome, Italy.

In September, 1962 he began dental school at Loyola University School of Dentistry (Chicago College of Dental Surgery) and was graduated on June 12, 1966 with the degree of Doctor of Dental Surgery. Following graduation he was accepted into a two year program at the dental school leading to a Master of Science and a Certificate of Proficiency in Oral Surgery.

On July 8, 1967 he married the former Nancy Jean Gracyk. While completing graduate school he concurrently served a six month residency in anesthesia at Franklin Boulevard Community Hospital.

In May of 1968 Dr. Skuble accepted a position as oral surgery resident at Hines Veterans Administration Hospital, Hines, Illinois.



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To Franklin Boulevard Community Hospital, for supplying and maintaining the monkeys used in the research project, and for the use of their research facilities and equipment.

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## Chapter I

### Introduction

While it is an established fact that the condyle contains the major growth center of the mandible, discrepancies appear in the explanation of facial and neurocranial bone changes after injury. Due to a lack of knowledge on how surgical procedures affect mandibular growth, more investigation is obviously needed to allow us to treat condylar injuries with some basic rationale.

For studies on the masticatory apparatus, the Rhesus monkey is often used because the gross and histologic pictures simulate those found in man. Up to this time experiments on the monkey condyle included removal, fracture and metatarsal bone grafts. However due to contradictions and varied explanations the use of this information is limited.

It is the purpose of this work to study on a long term basis the gross and histologic changes occurring in condylectomized animals.

Two studies on the condylectomized monkey have resulted in different findings. Guccione (1965) described a reconstructed condyle with a fibrocartilagenous cap. He observed active proliferation of cartilage in young animals with post operative periods extending to eight months. Sarnat (1959) in a thirty one month old post operative animal described a fibrosis from temporal bone to condylar stump.

Post operative periods in this experiment will range from two and one half weeks to eighteen months. Highlights of this work will include determining whether the time needed for repair and regrowth affects facial symmetry and occlusion and, finally whether any factors stand out in influencing the final histologic picture.

## Chapter II

### REVIEW OF THE LITERATURE

#### Normal Growth of the Condyle

In 1567 the physician Antonius Mizaldus published, in Paris, his observations that madder colors the bones of animals feeding on the plant. Almost 200 years later Louis Duhamel, a French physiologist and botanist, established the fact that when animal bones are stained with madder, the dye combines with the calcium in the bones.

Growth of the mandibular bone was first discussed in the work by John Hunter in his "On the Natural History of Human Teeth" (1771). He related that the mandible increases in length along the posterior border with some modeling resorption occurring at the anterior of the coronoid and condyloid processes. Hunter figured the mandible to grow in height by alveolar bone but mentioned nothing about the condyle as a growth center.

Almost a hundred years later Kolliker (1853) thought the condyle to grow exactly as an epiphyseal cartilage by noting a thick cartilagenous layer on the condyle head.

Tomes (1859) noted that the malalignment of teeth due to alveolar growth was compensated for by growth at the mandibular articular process.

Humphrey (1864) in his work with pigs noticed an anterior resorption and posterior apposition of bone to the ramus by the placement

of wires in the bone and their subsequent movement anteriorly.

Low ( 1909 ) studying sections of fetal heads noticed the cartilage at the heads of the condyles and its ossification but failed to mention anything regarding its significance as the primary growth center.

Brash ('24, '28 ) noted the upward growth of the condyle in madder fed pigs. Other observations included mandibular growth on all borders except the anterior of the coronoid, a posterior extension of the ramus; and the conclusion that lower molars move upward, forward and out.

Charles ('25, '30 ) in his work on the growth of the mandible offers one of the more accurate accounts of growth when he states, "The mandible grows by additions to the base of the cartilagenous wedge or cone of chondroblast bone, which appears at the fifty-five mm. stage of the fetal life. The growth of the angle and coronoid process is subsidiary to the main line of growth of the wedge which is in an upwards, outward and backward direction, the mandible therefore traveling in a downward and forward direction.

Brodie ( 1941 ) in his cephalometric study emphasized the importance of the condyle as a highly active growth center and the last bone of the head to lose this potential.

Rushton ( 1942 ) in his histologic study of condylar growth found the condyle to grow by apposition of cartilage until about the age of twenty whence the marrow spaces are separated from the pre cartilagenous

layer by a plate of bone.

Sicher ( 1945 ) clearly explained the mechanism of condylar growth. He states that "By the condylar growth the over-all length of the mandible increases, not however, the length of the mandibular body. In the condylar growth the growth of the cartilage, and not its replacement by bone, which makes the mandible grow in height and over-all length, just as a long bone grows in length by proliferation of the epiphyseal cartilage." "Analogy between the byaline cartilage in the mandibular condyle and the hyaline cartilage of the epiphyseal plate of the long bone does not exist. A cartilagenous epiphyseal plate of the long bone is interposed between the bony diaphysis and epiphysis. In the direction of the long axis of the long bone, this cartilage grows only interstitially. In contrast to this type of growth of an epiphyseal cartilage, the condylar cartilage of the mandible grows in all dimensions, at least partly by apposition."

#### Growth of the Monkey Mandible

Up until the last few years little work was published on the anatomy of the Rhesus monkey. Moore ( 1949 ) studied the growth of the monkey cranium but contributed little to the knowledge of mandibular growth.

Baume ( 1951 ) reported an article on the post natal growth of the mandible in the *Macaca mulatta*. He found that growth occurred on all surfaces of the lower jaw with the most stable region below the mandibular

canal at the second bicuspid region.

The major growth center was located in the endochondral cap of the condyle. The functions of membranous bone formation, resorption, and apposition at muscle insertions was found to be performed by tendinous perimysia.

Schwartz and Juelke ( 1955 ) studied the morphology of the head and neck of the Macaca monkey.

Zielinski ( 1965 ) dissecting the Macaca monkey found the gonial angle to flare medial rather than lateral as in man. He attributed this to the higher attachment of the deeper head of the masseter muscle permitting the medial pterygoid to exert a pronounced pull. Other observations included a shallow sigmoid notch and similar mandibular movements and histologic picture to man.

#### Observations on Experimental Condylar Injuries

Few experiments have been performed on the monkey temporomandibular articulation in an attempt to establish a better understanding of the repair process following condylar injury. Some of the basic problems are: whether the ensuing repair in the condylectomized animal will establish normal function and histology; whether the time of repair will affect mandibular growth on the operated side; whether the loss of bone continuity will disrupt the dentition; and whether a rationale can be advanced for the appearance of cartilage.



Sarnat and Engel ( 1951 ) performed one of the first recorded condylectomies on the *Macaca mulatta*. Their observations show an anterior open bite on the bilateral operated animals and the shifting of the mandible to the operated side on the unilateral operated animals.

Cephalometrically a failure in ramus height growth, a remodeling of the posterior ramal border and slight pre-angular notching was noticed on the surgical side. Some post operative observations included positioning of the posterior superior border of the ramus anterior to the glenoid fossa, absence of a capsule, shortening of the post glenoid process and loss of the articular disc in some of the cases.

They noted that "In the area of resection a thickening of the bone was found, particularly on the medial. This seemed to be an attempt at a reduplication in those animals of a longer post operative survival period."

On the operated animals the coronoid tip extended above the zygomatic arch while on the unoperated animals the height was at the same level. The distance from the coronoid tip to the lower border of the mandible was essentially the same in both cases. A reorientation of trabecular patterns was found radiographically on the operated animals.

Jarabak and Kaminis ( 1952 ) have shown that condylar regeneration takes place in rats and they state that the superficial diagonal fibers

of the masseter muscle maintain the anterior position of the mandible after surgery.

Jarabak and Stuteville ( 1952 ) later did bilateral condylar resections and found an open bite from canine to canine, filling in of the articular fossa and a concavity on the anterior incline on the eminence of the temporal bone. They found a pseudo-articular fossa to accomodate the condylar stump.

Still later Jarabak and Vehe ( 1952 ) did condylectomies on the rat followed by a sequential sacrifice of the animals. They report that loose connective tissue appeared in the defect by the ninth day, that cartilage appeared on the sixteenth day, and that the cartilage above the stump organized by the twenty eighth day.

They found that the amount and length of the regenerated condyle was dependent upon the width of the capsule.

Sarnat ( 1959 ) reporting on an extension of his previous work ( 1951 ) extended the post operative periods to twenty five and thirty five months with a histologic section of the thirty one month post operative animal. No chondrogenic zone giving rise to bone in the formed false joint was seen. The area above the boney stump beneath the articular space filled with fibrous tissue.

Tomek ( 1959 ) removed condyles in the Macaca monkey with resultant facial deformity in the seventeen month old animals.

Walker ( 1960 ) using the submandibular approach produced bilateral and unilateral fracture dislocations in monkeys with post operative periods ranging from sixteen to twenty months. He found that in animals with the jaws wired, attachment of the masseter occurred at its point of detachment. In the mobilized animals the masseter attachment occurred higher and the angle of the mandible subsequently curved inward from the action of the medial pterygoid. Final results showed all monkeys including one condylectomy had some type of functioning condyle. No open bites were present. Walker felt that the fracture dislocations healed with the condyle being resorbed from the medial and formation of a new condyle.

Jolly ( 1961 ) studied histologic sections of condylectomy in the rat finding an early chondroid bone formation. Interestingly he found early bone ossification points at the lateral pterygoid muscle insertion and on the cut surface of the ramus. In his study the distance between the skull and the cut end of the ramus was maintained.

Herzberg and Sarnat ( 1962 ) in a radiographic study on the condylectomized monkey noticed a change from the normal N-Pattern of trabeculae in the ramus.

Ware ( 1965 ) replanted condyles after surgical removal and found no alteration in maturation patterns. He observed the cartilage layer to be thinner on the operated side.

Guccione ( 1965 ) performed condylectomies on young Macaca monkeys and reported a normal histologic picture following post operative periods of four to eight months. No mention of mandibulo-facial deformity was made.

Peskin and Laskin ( 1965 ) using young dogs with condylectomies, hemicondylectomies and contralateral hemicondyle grafts concluded that: ( 1 ) Condylectomy markedly retards growth with only a functional condyle forming without the presence of cartilage. ( 2 ) Partial resection of the condyle initially retards mandibular growth but with condylar regeneration, growth then proceeds. ( 3 ) Contralateral autogenous grafts heal to the condylar stumps and participate in normal condylar growth.

Hayes ( 1967 ) performing unilateral condylectomies in the rat explained repair in this area stating, "It is conceivable that part of the chondrogenic layer, or even a single row of cells was stripped from the head of the condyloid process during condylectomy."

Boyne ( 1967 ) studying osseous repair after displaced subcondylar fractures found the displaced condylar heads actually repositioned themselves and did not resorb and reform as Walker reported ( 1960 ).

Boyne reasons that "The temporomandibular joint aids in the reduction and realignment of a displaced condylar fracture. The attachment of the capsule to the lateral and medial poles of the condyle is not easily

detached or torn by the fracture producing trauma. This fibrous attachment aided by muscular movement serves to gradually reposition the fractured fragment. The condylar growth center remains active and remodeling reforms the condylar fragment into acceptably osseous form."

## Chapter III

### Materials and Methods

#### Animals

Eight Rhesus monkeys purchased from Shamrock Farms Inc. of Middletown, New York were used in this research project. Seven of the animals were approximately four to six months of age and weighed between four to seven pounds each. The eighth animal was approximately thirty months of age and contained a full adult dentition. This animal weighed thirteen pounds.

The experiment was times so that a bilateral and unilateral operated animal could be sacrificed at eighteen months post operatively. The exact times and types of operation are listed completely in Table I. The animals were housed in separate stainless steel cages in a room maintained at about eighty degrees. They subsisted on the Rockland Primate diet supplemented daily with oranges or bananas.

#### Anesthesia

Using intravenous Nembutal Sodium (Abbott ) supplemented by 1% Xylocaine infiltration, anesthesia followed an injection of 50 mg. of the barbiturate into the great saphenous vein. In some instances where handling of the animal was difficult, 100 mg. was injected into the peritoneal cavity. Anesthesia was effected within fifteen minutes in most cases.

Guccione ( 1965 ) used 50 mg./cc/ concentrations per five lbs. of animal weight. It was noted that in the animals not given the local anesthetic, a supplemental dose of barbiturate was needed.

### Photography

Photographs of the animals and surgical procedure were taken with a 35 mm. Nikon camera having the Medico-Nikor lens. Two-thirds magnification was used for the color prints. Both panatomic-X and Kodacolor-X film was used for the photographs. Photomicrographs were taken with a 35 mm. Zeis camera using panatomic-X film.

### Pre Operative Records

Pre operative records included age, weight, sex, time of operation, dentition, deviations and surgical sides.

### Surgical Procedure

After intravenous injection of the barbiturate the side to be operated was shaved and the area infiltrated with local anesthetic. Following a Phisohex scrub a vertical incision measuring two and one-half centimeters was made via the preauricular approach. With retraction of the parotid gland and careful dissection protecting the branches of the facial nerve, the zygomatic arch was followed above the area of the articular fossa. On exposure of the capsule a vertical incision followed to bone exposing the condyle.

Using a #701 fissured bur with sterile saline as a coolant, an

incomplete cut was made through the surgical neck of the condyle. With a blunt elevator the condyle fractured from the ramus. After rotating and reflecting the condyle, the lateral pterygoid muscle was either torn or cut from the condyle. The condyle was removed. In all animals except one was the disc intentionally left in place. The deeper layers were closed with 3-0 chromic catgut and skin closure followed with 5-0 nylon. Dressings or prophylactic antibiotics were not used. No type of skeletal fixation was used.

#### Sacrifice and Post Operative Procedure

After the designated post operative periods, the animals were anesthetized and sacrificed by perfusion into the heart with 10% formalin. The heads were removed and the dentition examined. The soft tissues excluding the temporomandibular joint area were dissected from the skull. The animals were photographed, the skulls hemisected, and radiographs were taken.

#### Radiographs

The skulls were hemisected with a band saw to facilitate radiographs. The radiographs were taken at 40 inches with the kilovoltage set at 90 and the milliamps at 15. Exposure time was set at one and one-half seconds.

#### Histology

After the necessary observations and radiographs the temporomandibular



articulation was removed with a #560 carbide bur. The blocks were decalcified with a 10% solution of formic acid, washed in water, dehydrated with concentrations of ethyl alcohol, cleared in chloroform, and embedded in paraffin. Frontal sections ranging from six to eight microns were stained with hematoxylin and eosin and mallory stain.

## Chapter IV

### POST OPERATIVE FINDINGS

Following surgery all animals recovered from the anesthetic within one to two hours. Movement of the jaws was not impaired especially in the unilaterally operated animals. In this group a noticable swing to the operated side was seen on opening.

The bilateral operated animals opened in an even plane but the amount of opening was limited.

It was found from earlier experiments that the animals tended away from the hard food pellets, so the primate diet was softened with water. All animals gained weight after surgery and did not appear hindered in the normal masticatory patterns.

Post-surgically the animals were not placed on antibiotic therapy. As long as two days post surgically the animals remained somewhat lethargic but thereafter resumed the quick alert movements peculiar to the monkey.

A few unpredictable occurrences found in this experiment reveal some interesting physiologic changes following a surgical procedure. In one animal ( #3 ) with a unilateral condylectomy a deviation to the unoperated side was seen eighteen months following surgery. In an animal ( #6 ) where a bilateral condylectomy was performed in two stages with an interim of four months, an interocclusal space of two and one-

half mm. developed between all posterior teeth on the initial side of surgery.

### Post Mortem Findings

Animals # 1 & 7 ( normal controls )

The normal control animals were sacrificed at approximately eighteen and twenty six months of age. Bilateral facial symmetry was noted in both animals.

Zygomatic Arch and Masseter Muscle. -- The zygomatic arch in the control animals consisted of thin blade of bone connecting zygoma with the temporal bone. Topical views of the skull showed the thin zygomatic arch starting at the temporal process of the zygoma and flaring medial and posterior into the temporal bone at the suparticular crest. It maintained itself at a certain distance away from the skull. From the suparticular crest medial to the temporal squama, a wide concavity distanced an area about one-half the width of the condylar head.

The masseter muscle originates from the zygomatic arch by a heavy tendinous attachment. The posterior extension of its attachment on the arch is anterior to the condyle. It appears the masseter is in a more vertical plane than that found in man. Dissection of the temporalis muscle revealed a union of the latter with the masseter along the anterior one-third of the zygomatic arch.

Temporalis Muscle and Fascia of the Temporal Area. -- In the monkey

the fascia covering the temporal area splits into a superficial and deep layer which attach to the outer and inner surfaces of the zygomatic arch respectively. The soft fat between the layers is contiguous with that of the buccal fat pad. The fascia covering the temporal squama acts as a suspensory mechanism for the zygomatic arch. Dissection of the temporal muscle showed the short fibers arising from the zygomatic arch.

Dentition. -- Both control animals had erupted permanent central incisors and first molars at sacrifice. No midline deviation was present and a normal occlusion of posterior teeth was noted. The deciduous molar teeth showed wear facets in both specimens.

Ramus. -- The condyloid and coronoid processes are superior extensions of the ramus. The coronoid process with its attachment of the temporal muscle insertion extends to a level equal to the superior border of the zygomatic arch. The condyloid process extending not quite as high as the coronoid but in a more posterior medial direction articulates through a disc with the temporal bone. Due to the histologic blocks taken from this articulation a dissection was not performed. No antegonial notch was present in the control animals.

#### Animal #2

A unilateral condylectomy was performed on the left side of this animal. Rather than maintain this animal for the long post operative periods, it was sacrificed twenty days following surgery. It was thought

that some evidence on early repair in the monkey would be helpful in the evaluation of the final results.

Zygomatic Arch and Masseter Muscle. -- In this animal at the early sacrifice date, a notable thickening of the zygomatic arch was observed when compared to the opposite side. This thickening occurred midway along the arch between zygoma and temporal bones. A topographic view of the dissected animal showed a slight constriction of the zygomatic arch medially. The masseter muscle maintained a tough tendinous attachment to the zygomatic arch and conjoined with the temporalis muscle at this level.

Temporalis Muscle and Fascia of the Temporal Area. -- Attachment of the temporalis muscle and fascia covering the area compared with the normal control animals.

Dentition. -- There was a slight midline deviation after such a short post operative period. All deciduous teeth were present and in good alignment.

Ramus. -- A slight elevation of the coronoid process above the zygomatic arch was noted. A frontal view of the dissected animal showed no medial deviation of the anterior surface of the ramus. From this view bilateral symmetry was present. It was the purpose of early sacrifice to histologically evaluate initial repair in the new temporomandibular articulation.

### Animal #3 ( Unilateral Condylectomy )

This animal was the longest post operative specimen in the unilateral operated group. It is of particular interest that after a sixteen month post operative period, the expected results did not occur.

Zygomatic Arch and Masseter Muscle. -- On the unoperated side the zygomatic arch consisted of a thin bone that ran directly across from zygoma to temporal bone in a relatively straight course. This was also seen in normal controls. The origin and insertion of the masseter muscle was likewise the same as in the normal controls.

On the operated side a wide upward arching of the zygomatic arch midway along its course appeared. Topical views of the dissected skull showed a marked medial curving of the zygomatic arch especially in the area of the suparticular crest.

Temporalis Muscle and Fascia of the Temporal Area. -- The muscle and fascia of the temporalis followed that seen in the normal controls.

Dentition. -- The interesting and unexpected occurrence in this animal was a five mm. midline deviation of the mandible to the unoperated side. In past experiments and in surgical procedures in humans, deviation would more likely be expected to the operated side. At the time of investigation and photography it was made certain that the mandible was in proper occlusion.

Ramus. -- The width of the ramus appeared equal in thickness on both sides. From a lateral position the level of the coronoid process was about the same height above the arch as that on the unoperated side. However the arch on the operated side was twice as high ( approximately five mm. high ) in a superior-inferior dimension. This would account for approximately a five mm. superior deflection of the coronoid process.

#### Animals # 4 & 5 ( Bilateral Condylectomies )

Since similar results occurred in both animals with bilateral condylectomies the gross description of the two will be found in this section. In general, deviations from the normal occurred in both animals with accentuation of changes more described on the longer post operative animal. Post operative periods were fourteen and eighteen months with the age of the animals at sacrifice approximately twenty-three and twenty-five months respectively.

Zygomatic Arch and Masseter Muscle. -- Viewed laterally the zygomatic arch in both animals showed a higher arching and a thicker width than the normal controls but similar to the arches of unilaterally operated animals. Topical views of these animals did not show much, if any, medial displacement of the arch.

No change in the origin or insertion of the masseter muscle was found. In all animals operated a bowing upward of the masseter between the zygomatic arch and ramus was present. Due to the condylectomy in

the area this apparently was an accentuation or upward presentation of the temporal-masseter muscle ( Sicher ).

Temporal Muscle and Fascia of the Temporal Area. -- Changes in the attachment of the temporal muscle and fascia covering the area were not apparent.

Dentition. -- In both animals a midline deviation was present. In the eighteen month post operative animal a one mm. discrepancy of the mandible to the right appeared. In the fourteen month post operative animal a three mm. difference was noted. In both instances bilateral condylectomies were performed at the same time.

Ramus. -- When viewed frontally the anterior border of the ramus appeared more medial to the skull. The coronoid process in both animals extended slightly above the curved zygomatic arch.

#### Animal #6 (Bilateral Condylectomy )

This animal was not described with the previous bilateral condylectomies because the surgery on either condyle was performed in two stages with an interim of four months. The total post operative times for each side was ten and fourteen months with the animal sacrificed at twenty-three months.

Zygomatic Arch and Masseter Muscle. -- Equal thickening and arching of the zygomatic arch was observed bilaterally. Topical views did not show the medial constriction of the arch which up to this time was seen



only in unilaterally operated animals. The masseter muscle maintained a tough tendinous attachment to the zygomatic arch.

Temporalis Muscle and Fascia of the Temporal Area. -- No changes from the normal control animals were observed.

Dentition. -- An interesting phenomenon occurred in the dentition of this animal. At the time of sacrifice the only teeth in occlusion of this animal were the posterior teeth on the left side. The latter side was the last to be operated. Four months previous the right side condylectomy was performed. This side showed a two and one-half mm. interocclusal space with no posterior teeth in occlusion.

Ramus. -- The anterior border of the ramus from an A-P view was symmetrical in shape, direction and medial placement from the skull.

Animal # 8 ( Unilateral Condylectomy - adult animal )

At surgery this animal contained a full complement of permanent teeth and was used as an adult predictable type. Since surgery on the monkey condyle has in the past been performed on relatively younger animals, perhaps differences in repair would ensue in adult animals with little condylar growth ahead.

Zygomatic Arch and Masseter Muscle. -- The zygomatic arch on the unoperated side could be described as that found in the normal control animals. The operated side was disfigured to such an extent that an unexplainable exophytic growth formed upward on the supraparticular

crest. The boney growth jutted upward in an upright "T".

The masseter muscle was attached to the temporalis muscle in a region of the first one-third of the zygomatic arch and interposed between the arch and coronoid process.

Temporalis Muscle and Fascia of the Temporal Area. -- As previously mentioned the temporalis and masseter muscle were attached to one another in the region of the first one-third of the zygomatic arch. The fascia covering the temporal area attached as in the normal controls.

Dentition. -- This animal deviated to the operated side on opening and lagged to the same side on closing. After closure a normal occlusion was observed. The plane of the dental arch and the alignment of teeth showed no observable changes.

One understandable occurrence was the loss of a first permanent premolar tooth on the operated side. The adult monkey canine teeth are extraordinarily long with especially long roots. In the early post operative periods deviation to the side of surgery with subsequent occlusal trauma probably avulsed the tooth from the arch.

The permanent first molar was also absent on sacrifice leading us to believe that enormous pressures are absorbed by the dentition following the loss of the pressure bearing condyle.

Ramus. -- An anterior "bending" of the posterior ramal border as it approached the condylectomy area was observed on the operated side.

The posterior surface of the ramus on the unoperated side approached the condylar area in a superior posterior direction common to the normal control animals.

TABLE I

## PRE OPERATIVE RECORDS

Animal #	Sex	Age (approx.)	Wt. (Lbs.)	Midline	Side of Surgery	Post Op Period	Age at Sacrifice
1	Male	7Mo.	6.75	normal	Control	----	18 Mo.
2	Female	6Mo.	7.00	normal	Left	2.5 Weeks	6 1/2 Mo.
3	Female	7Mo.	6.00	normal	Left	18 Months	25 Mo.
4	Male	9Mo.	8.00	normal	Bilateral	14 Months	23 Mo.
5	Female	7Mo.	6.3	normal	Bilateral	18 Months	25 Mo.
6	Male	9Mo.	7.75	normal	Bilateral	Rt. 14 Months Lt. 10 Months	23 Mo.
7	Male	8Mo.	7.5	normal	Control	----	26 Mo.
8	Female	24Mo.	.13	normal	Left	10 Months	34 Mo.

PLATE I

Animal # I (Normal Control)

Figure I. (Left) Topical view of left zygomatic arch.

Figure2. (Right) Topical view of right zygomatic arch.



PLATE II

Figure 3. Right zygomatic arch.

Figure 4. Left zygomatic arch.

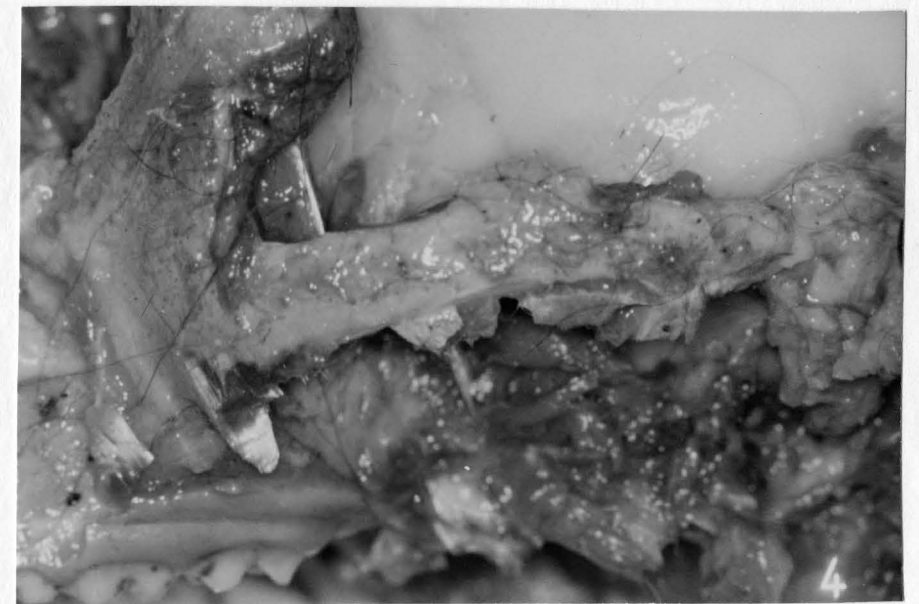


PLATE III

Animal # 3 ( Left Condylectomy)

Figure 5. ( Top ) Dentition .

Figure 6. (Bottom Left) Left zygomatic arch .

Figure 7. (Bottom Right) Right zygomatic arch.

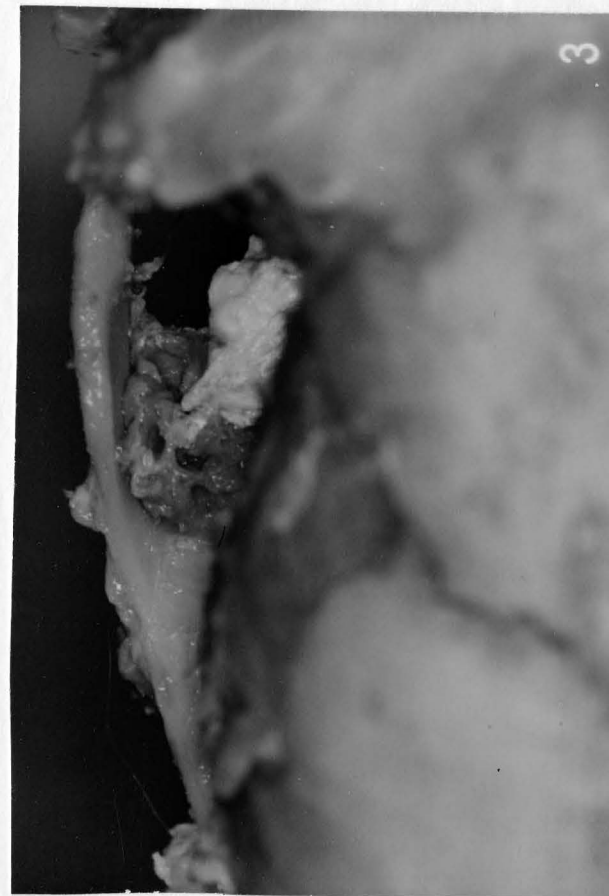




PLATE IV

Figure 8. Right zygomatic arch.

Figure 9. Left zygomatic arch.

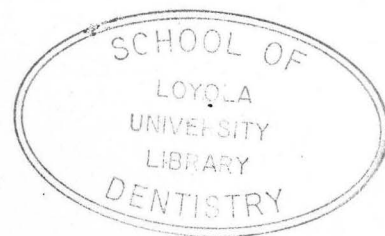




PLATE V

Animal #4 (Bilateral Condylectomy)

Figure I0. (Top) Dentition.

Figure II. (Left) Left zygomatic arch.

Figure I2. (Right) Right zygomatic arch.



Figure I3. Right zygomatic arch.

Figure I4. Left zygomatic arch.

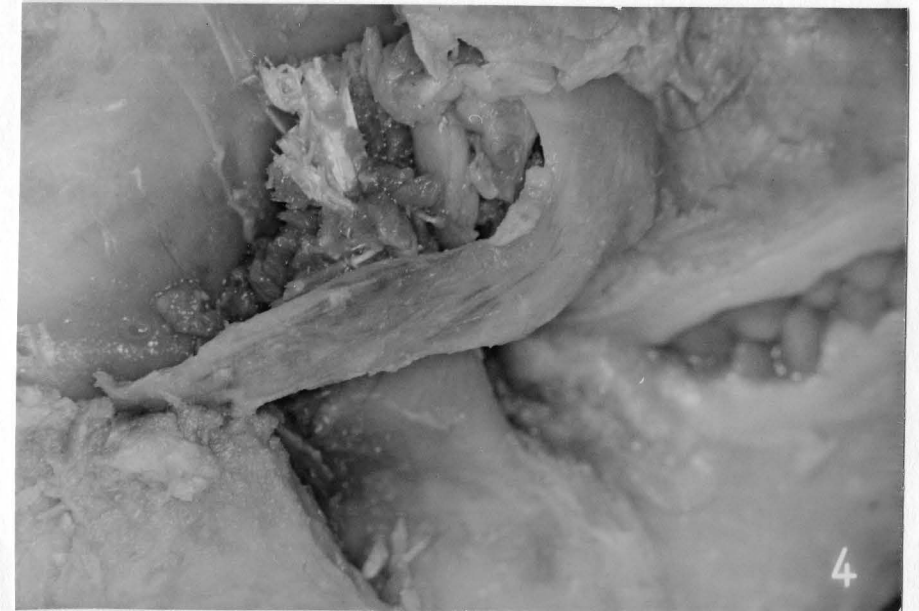


PLATE VII

Animal # 5 (Bilateral Condylectomy)

Figure I5. (Top) Dentition .

Figure I6. (Left) Left zygomatic arch.

Figure I7. (Right) Right zygomatic arch.

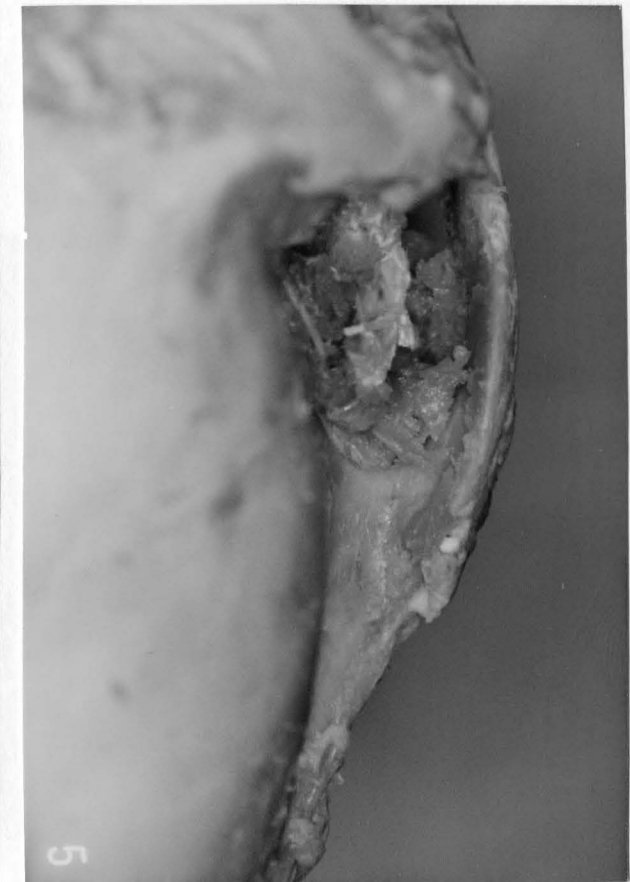




PLATE VIII

Figure I8. Right zygomatic arch .

Figure I9. Left zygomatic arch.

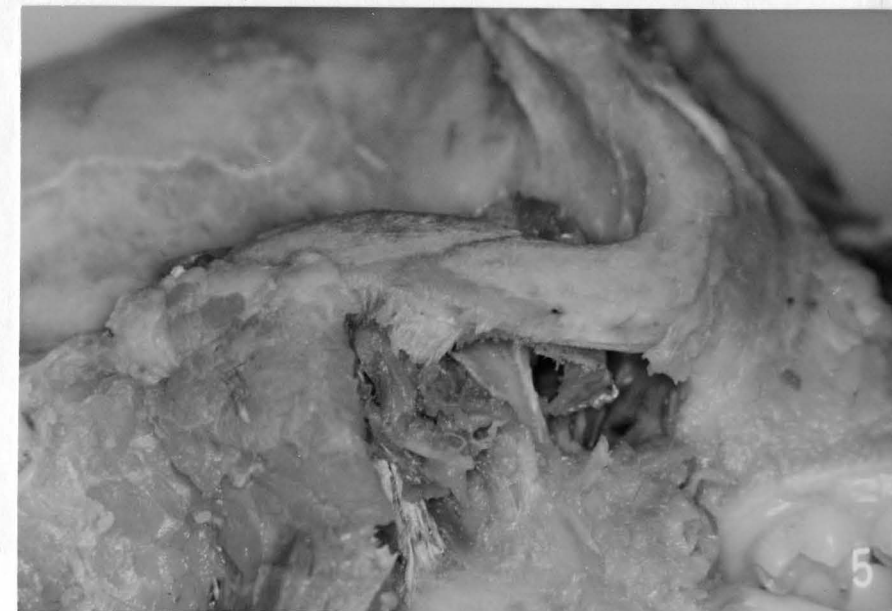


PLATE IX

Animal #6 (Bilateral Condylectomy)

Figure 20. (Top) Dentition.

Figure 21. (Left) Left zygomatic arch.

Figure 22. (Right) Right zygomatic arch.

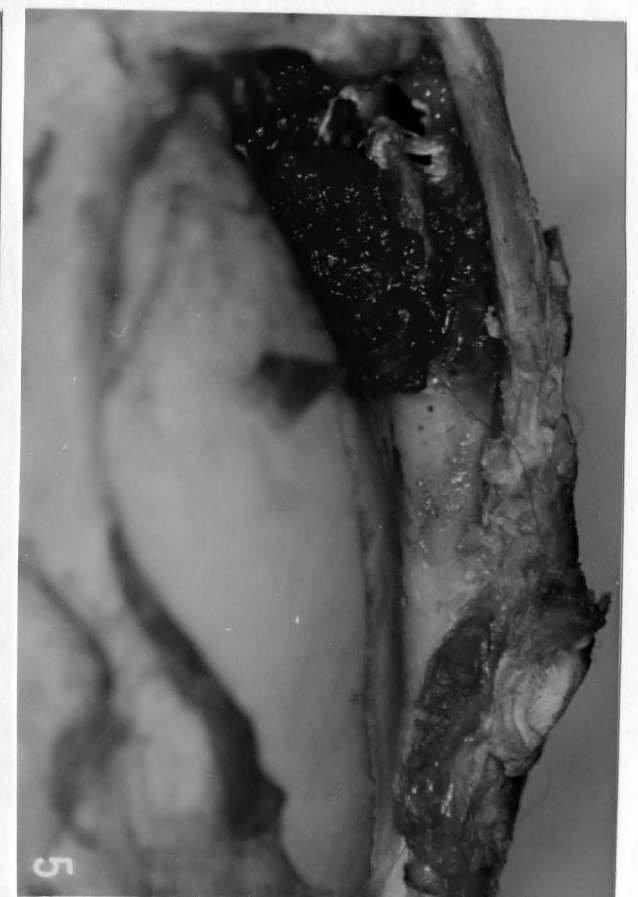


PLATE X

Figure 23. Right zygomatic arch.

Figure 24. Left zygomatic arch.

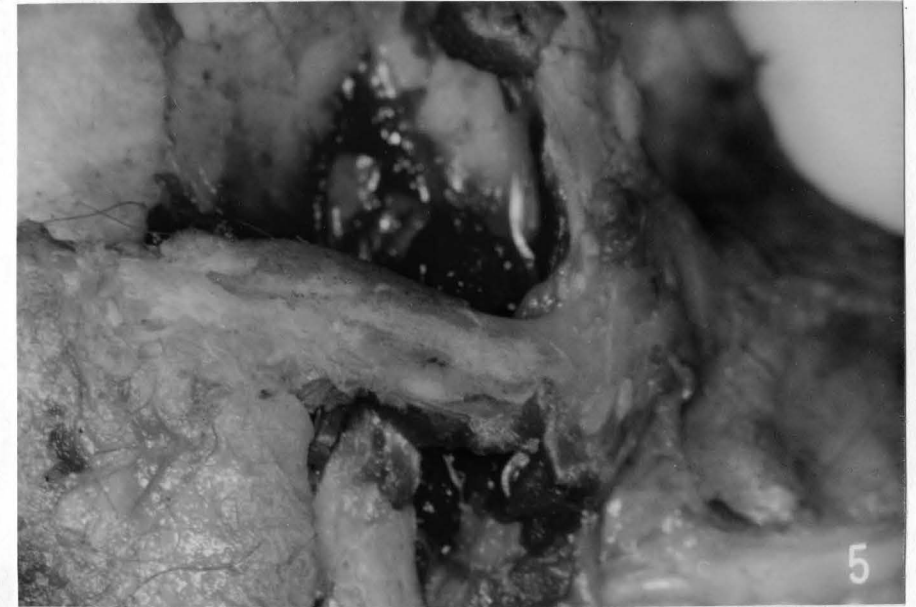




PLATE XI

Animal #7 (Normal Control)

Figure 25. (Top) Dentition.

Figure 26. (Left) Left zygomatic arch.

Figure 27. (Right) Right zygomatic arch.

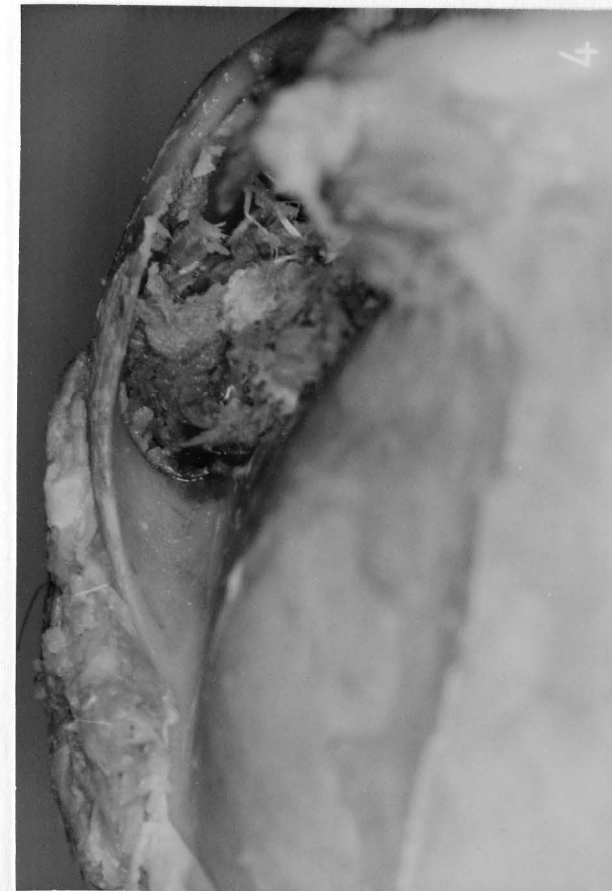


Figure 28. Right zygomatic arch.

Figure 29. Left zygomatic arch.

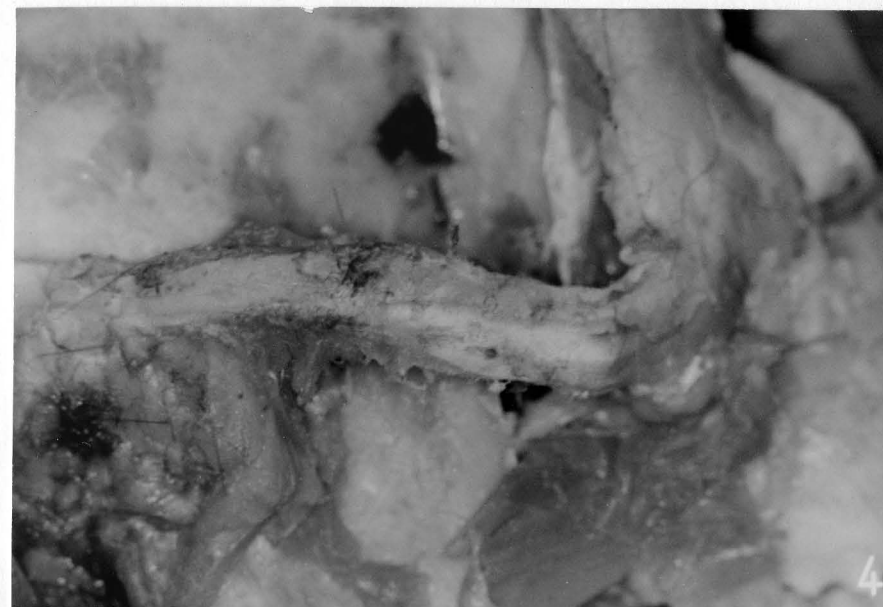




PLATE XIII

Animal # 8 (Unilateral Condylectomy)

Figure 30. (Top) Dentition.

Figure 31. (Left) Exostosis of left supramaxillary crest.

Figure 32. (Right) Exostosis of left supramaxillary crest.



Figure 33. Right zygomatic arch.

Figure 34. Left zygomatic arch.



Figure 35. (Top) Operated Temporomandibular Articulation.

Figure 36. (Left) Dentition-Right Side.

Figure 37. (Right) Dentition-Left Side.

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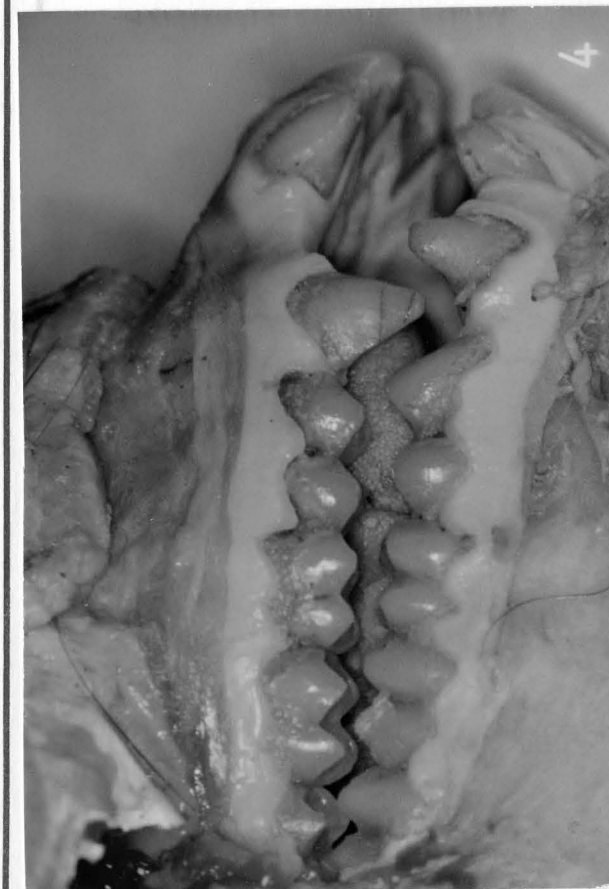
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the young animals. No antegonial notch was present.



fibrocartilage.



## Roentgenographic Findings

Control Animals. -- Roentgenographs were taken of the hemisected skulls before block removal of the temporomandibular articulation. The control animals showed a condyle in the articular fossa. No antegonial notch was present.

Unilateral and Bilateral Operated Animals. -- In all of the young operated animals there was roentgenographic evidence of a condyle within the articular fossa. No difference from the normal controls was noted in the young animals. No antegonial notch was present.

Unilateral Operated Adult Animal. -- Roentgenographs of this animal showed no formation of a functional condyle. A condylar stump remained as might be seen immediately following condylectomy. An anterior curving of the posterior border of the ramus was continuous with the sigmoid notch.

## Histology

Control Animals. -- Histologic sections of the temporomandibular articulation revealed findings comparable to a normal articulation. Between the articulation bodies of the temporal bone and condyle, a fibrous disc was present. The fossa of the temporal bone consisted of compact bone. The articular tubercle consisted of spongy bone covered by a fine line of compact bone. The entire surface was covered with a fibrocartilage.

The condyle consisted of spongy bone with a thin layer of compact bone above. From the superficial fibrous covering to the compact bone were present the following layers: ( 1 ) Pre-cartilage; ( 2 ) degenerating and calcifying cartilage; ( 3 ) resorbing cartilage; and, ( 4 ) bone formation. The capsule of the articulation consisted of a thick fibrous outer covering with a thin connective tissue inner layer.

Young Operated Animals. -- All of the young operated animals formed some type of functioning condyle. Histologically the typical layers seen in young control animals were present.

Adult Operated Animal. -- The adult operated animal showed no reformation of a functioning condyle. The condylar stump following surgery remained. Evidence of cartilage was not present in any condylar specimen on both the operated and unoperated sides. From the boney condylar stump fibrous connective tissue filled the space to the temporal bone.



PLATE XVI

Roentgenographs

Figures 38 & 39. Animal #1 Right and Left sides.

Figures 40 & 41. Animal #3 Right and Left sides.

Figures 42 & 43. Animal #4 Right and Left sides.

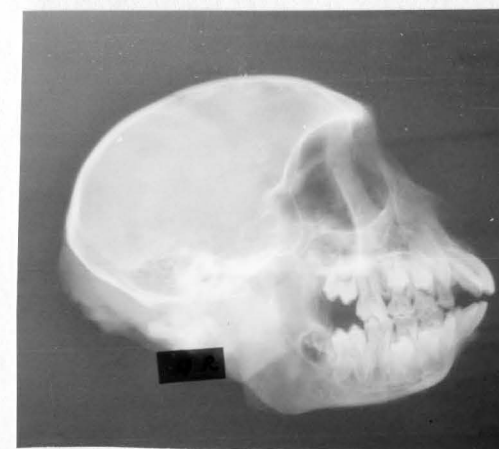


PLATE XVII

Figures 44 & 45. Animal #5 Right and Left sides.

Figures 46 & 47. Animal #6 Right and Left sides.

Figures 48 & 49. Animal #7 Right and Left sides.

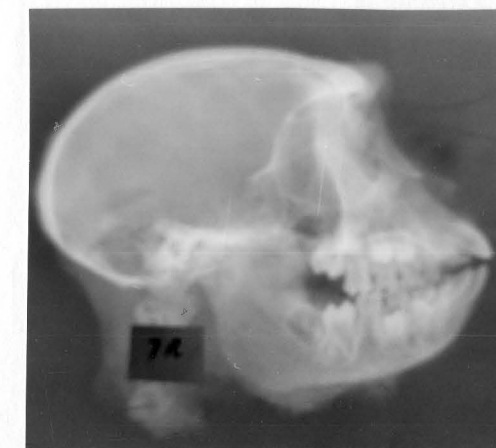


Figure 50. Animal #8 Right side.

Figure 51. Animal #8 Left side.





PLATE XIX

Photomicrographs

Figures 52 & 53. Animal #1 Right and Left sides.

Figure 54. Animal #2 Left side.

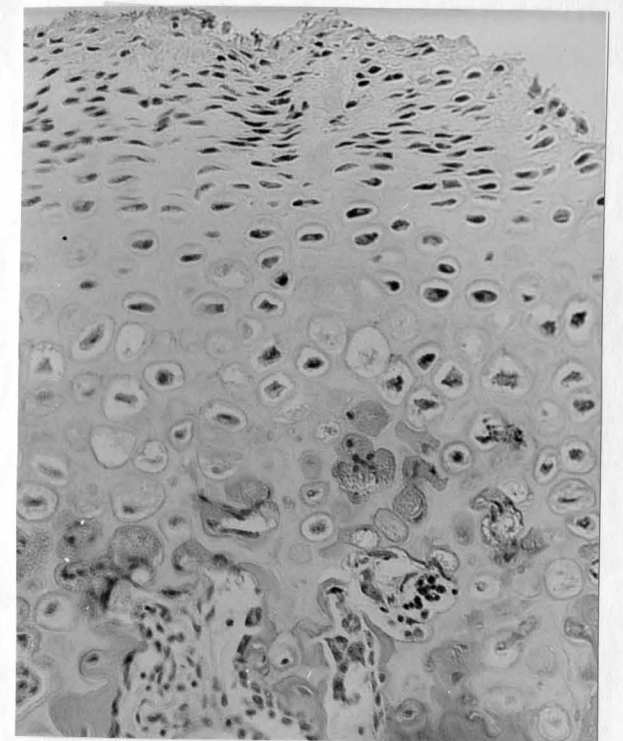
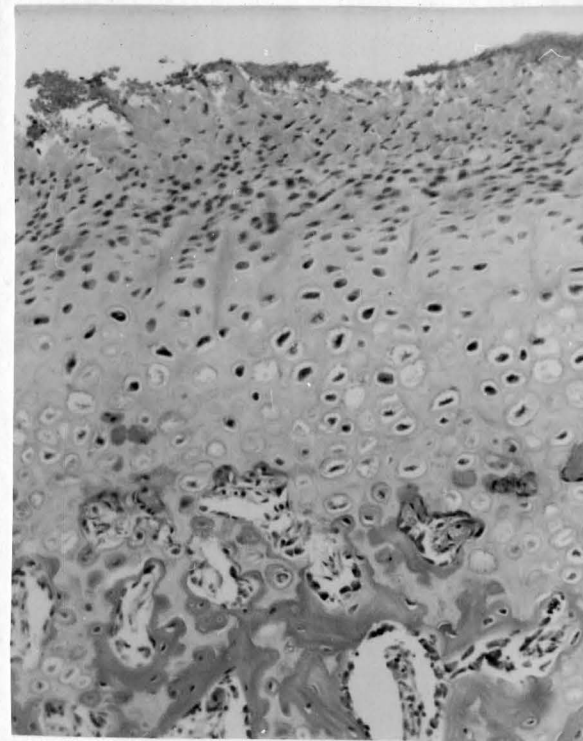


PLATE XX

Figures 55 & 56. Animal #3 Right and Left sides.

Figures 57 & 58. Animal #4 Right and Left sides.

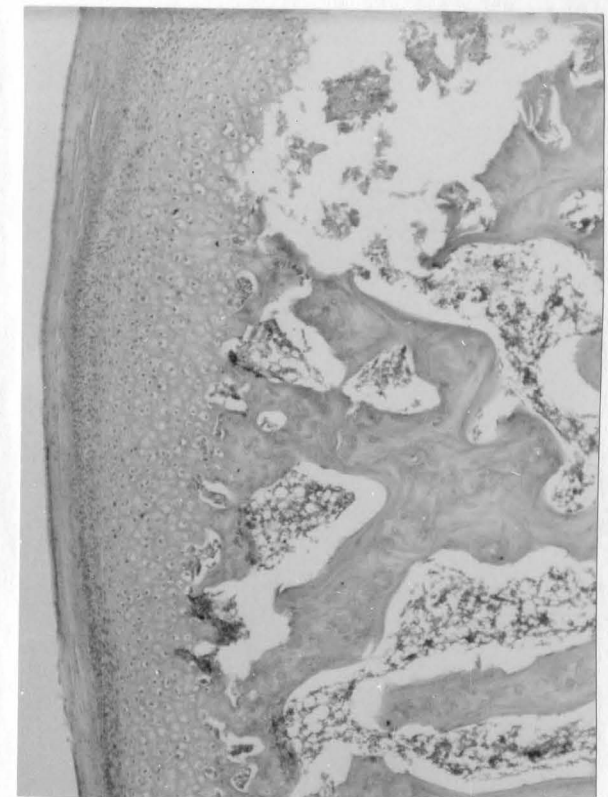
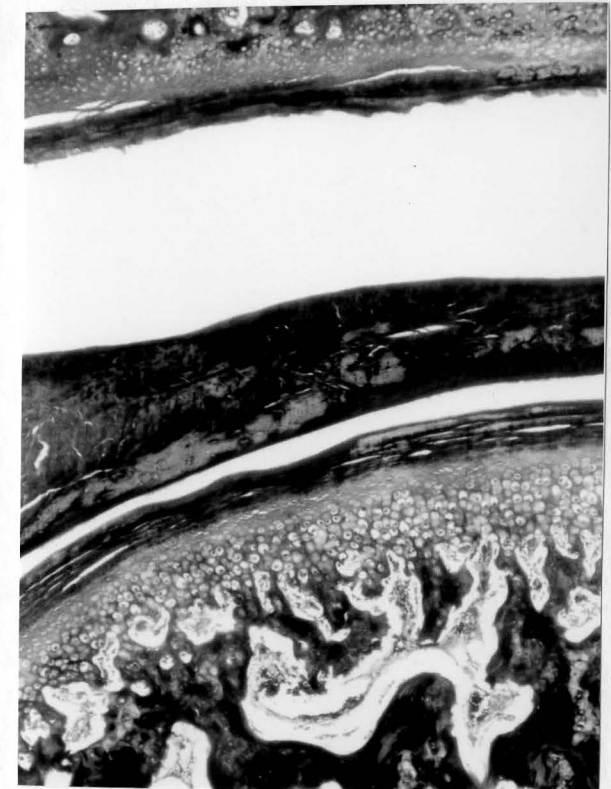
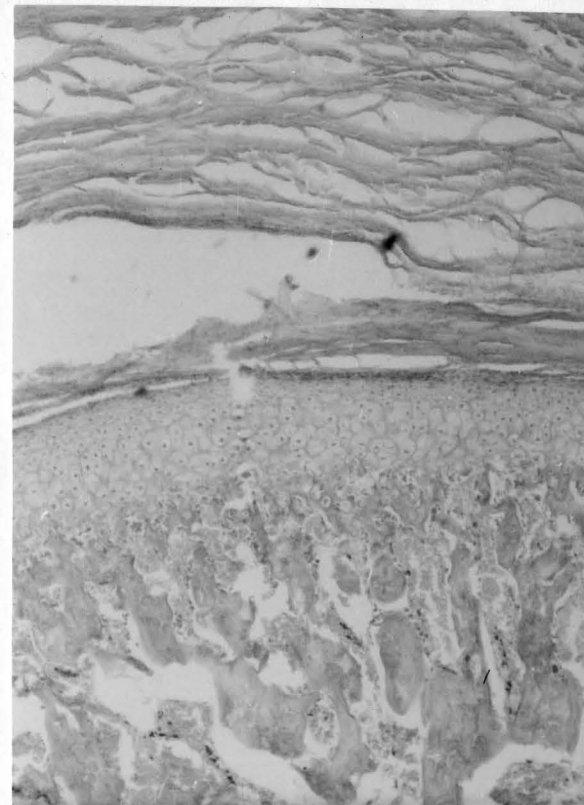
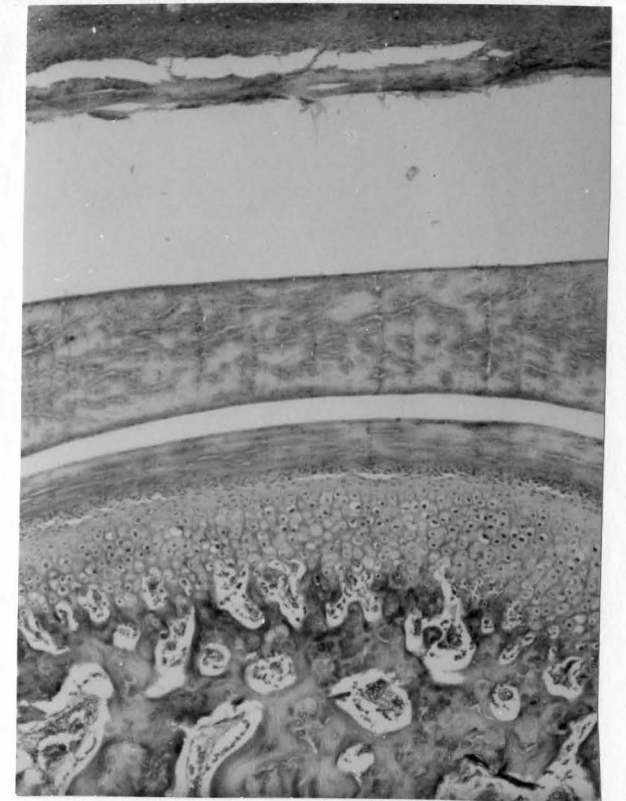
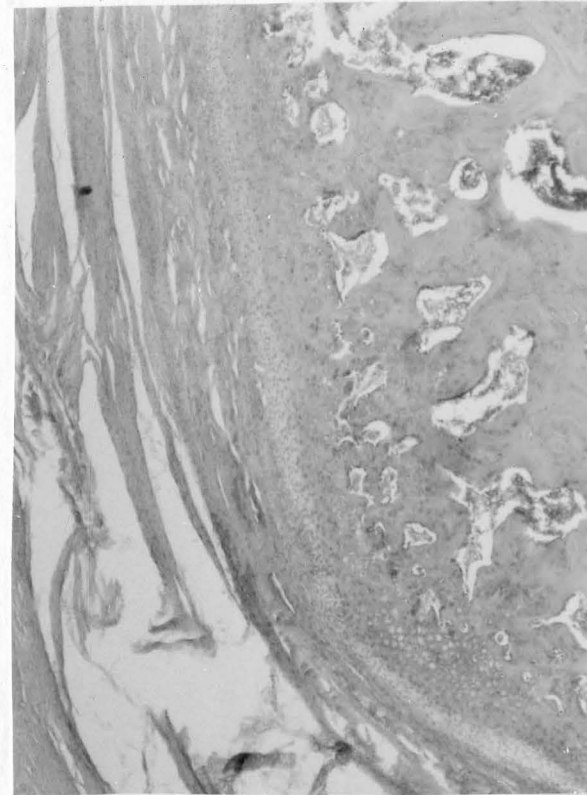




PLATE XXI

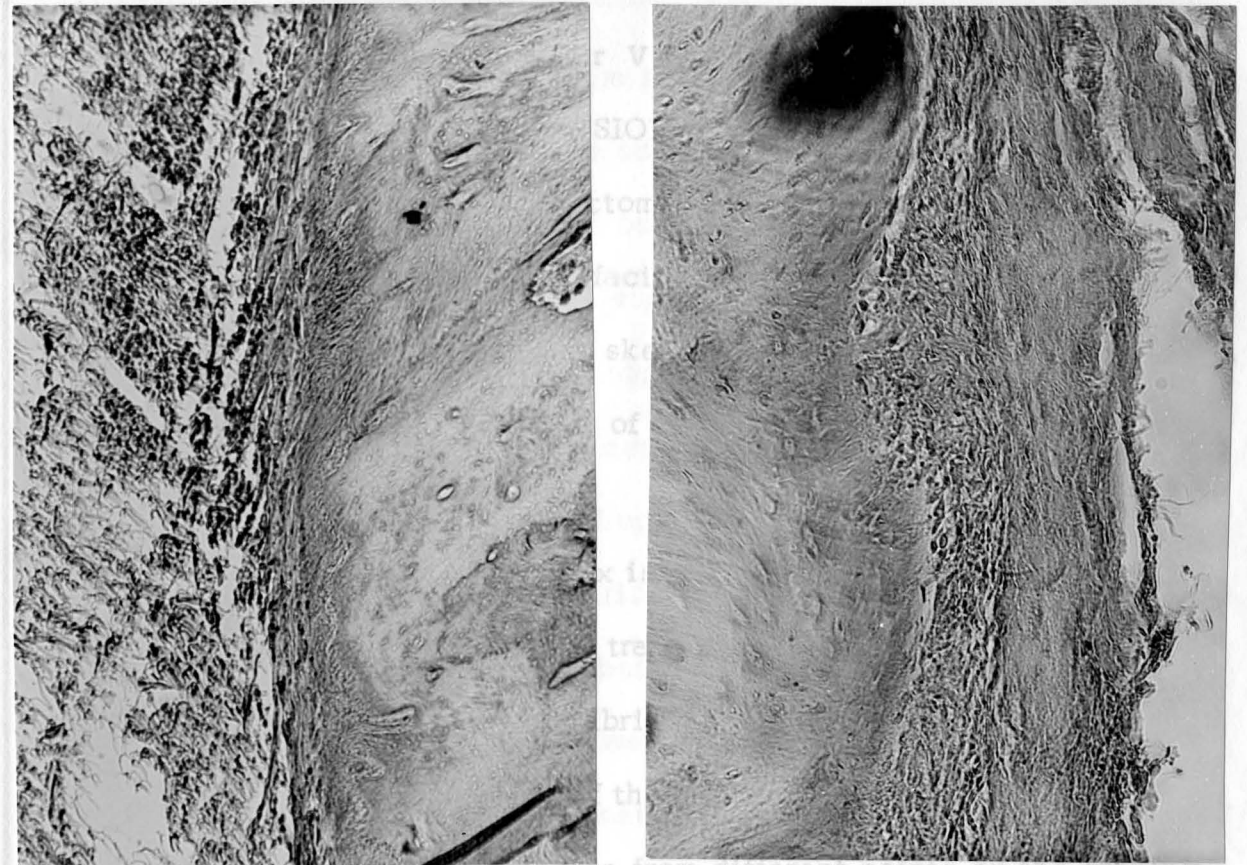
Figures 59 & 60. Animal #5 Right and Left sides.

Figures 61 & 62. Animal #6 Right and Left sides.



Figures 63 & 64. Animal #7 Right and Left sides.

Figure 65. Animal #8 Left side.



pterygoid and temporals originate from different points on the cranium and can act synergistically to produce powerful forces against the

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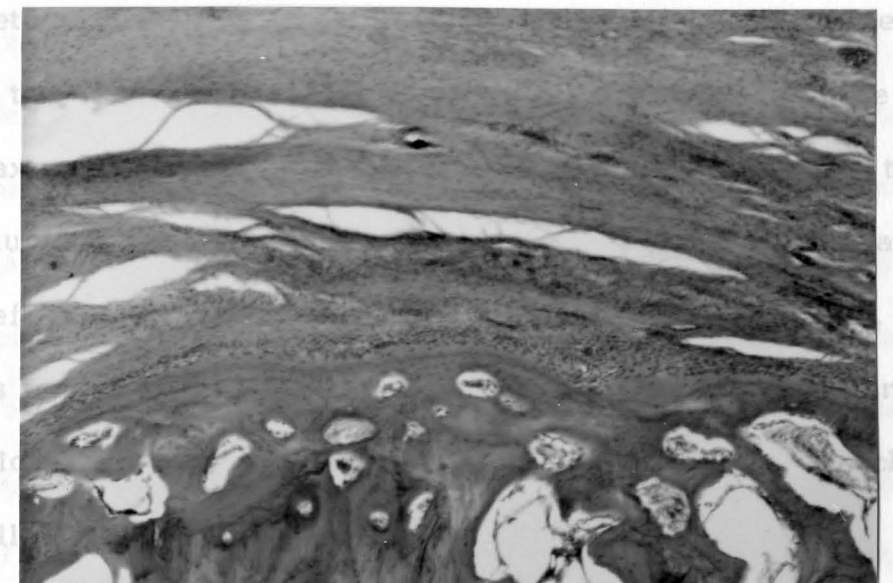
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The bone changes seen in the condylectomized animal of this study

## Chapter V

### DISCUSSION

Clarity in explainig condylectomy induced bone changes in the masticatory apparatus would be facilitated by a brief presentation of a functional analysis of the facial skeleton. Up to this time no reports in the literature explain the effects of condylectomy onthe resultant gross and histologic picture.

The craniomandibular complex is arranged in such a way that forces produced by the musculature and transmitted via the mandible to the cranium are in a system of equilibrium around the base of the skull.

The main elevator muscles of the mandible, the masseter, medial pterygoid and temporalis originate from different points on the cranium and can act synergistically to produce powerful forces against the upper teeth. The teeth through their ligments cushion to some extent and then transmit theremaining impact to the maxilla. From the alveolus of the maxilla three vertical pillars transmit occlusal forces to the base of the skull. The structure of the canine, pterygoid and zygomatic pillars reflect their function and consolidation around the orbit, nasal passages and sinuses. With any substantial change in the quantity or direction of occlusal force to the maxilla, changes in the architecture of the pillars could be expected.

The bone changes seen in the condylectomized animal of this study

are basically due to removal of the main pressure bearing area, the condyle. Removal of the condyle and the subsequent loss of bone continuity from ramus to temporal bone moves the condylar fulcrum to the posterior teeth on the side of surgery.

While no detectable changes appeared in the pterygoid or canine pillars, an upward bowing of the zygomatic arch was probably an adaptation to the stresses placed upon it. In the monkey, as in man, the zygomatic pillar follows superiorly from the basal portion of the alveolus in the molar region and buttresses posteriorly to the temporal bone. The bone changes visible were an actual bowing of the arch and an increase in its vertical thickness. No change was noted in the posterior teeth when compared to the opposite side indicating the added stresses were absorbed and tolerated by the teeth and maxilla in young animals.

Another important factor in the bowing of the arch lies in the pull of the masseter muscle. While the normal forces of occlusion tend to bow the zygomatic arch upward, the tension afforded by the masseter muscle counterbalances the biting force. In the condylectomized animal the loss of bone continuity shortens the distance from origin to insertion, aborting the amount of tension produced on the arch. This lessened amount of tension, enhanced by a change of fulcrum to the posterior teeth, exaggerates the size and shape of the arch in growing animals.

Loss of masseter muscle function probably accounts for loss of the lateral flaring of the zygomatic arch.

The temporal fascia attached to the inner and outer aspects of the arch simply functions as a suspensory fascia and evidences little or no change after condylectomy.

Following condylectomy, careful observation in the monkey dentition shows a different response in young animals when compared to adults. While the term young and old animals affords considerable leeway in time, the terms are used throughout this paper relative to the dentition present in the animals; the younger animals having a full compliment of deciduous teeth, and the older animals having nearly a full compliment of permanent teeth.

During the formation of a functional condyle all of the young animals showed a pronounced lag in the normal increment of mandibular growth. Observation showed a proportionately larger anterior open bite in the longer post operative periods. The older animal had relatively little condylar growth potential remaining. Evidence of this is seen in figure 30 where the open bite is not pronounced. The lag produced by removal of the condyle and the increased pressure on the posterior teeth undoubtedly assisted in the avulsion of the permanent first premolar and first molar. The musculature in older animals would also produce more powerful forces to aid in the disruption of the dentition. No

radiographic evidence of an extraction socket is present indicating early post surgical loss of the teeth.

### Condylar Reconstruction

Microscopically all of the young animals showed a functional condyle with a proliferating cartilagenous cap. The condylar stump of the operated adult animal along with the normal unoperated side showed no signs of proliferating cartilage. The area from the condylar stump to the glenoid fossa contained fibrous tissue.

In discussing repair following condylectomy it is necessary to point out that one need not have a residual layer of fibrocartilage to obtain appositional growth of cartilage. In much the same way that the bridging callus forms of fibrocartilage from the young connective tissue in a fracture, so too, the mechanical aspects typical of this area influence the type of tissue response.

The initial events after surgery are also seen in callus formation. Hemorrhage from severed blood vessels forms a hematoma in the surgical defect. In time organization of this hematoma follows into granulation tissue with the subsequent proliferation and invasion of capillaries into the clot. The pluripotential cells of the young connective tissue differentiate into macrophages and fibroblasts, removing necrotic debris from the area.

In the monkey, organization in the condylar defect occurs within a



a week since the area is of a relatively small size. During this time masticatory movements of the condylar stump influences the proliferating fibroblasts and their collagenous fibers. This stress orientates the collagenous fibers parallel to the joint surface followed by differentiation of young connective tissue into cartilage. The proliferating cartilage is stimulated by the intermittent pressure of movement and mastication, until the continuity between subchondral bone to glenoid fossa is bridged.

### Hypothesis

The fact that the young animals formed a functional condyle with a proliferating cartilagenous head and the adult animal formed a fibrosis from condylor stump to temporal bone is not as puzzling as might appear. The most important factor in tissue response to mechanical forces is the age of the animal, which, one might say, is proportional to the differentiation potential of its connective tissue. In older animals there appears to be a lessened ability to form cartilage.

In experiments upon the chick embryo, proof has been presented showing that without the normal function of muscles future articulations ankylosis. Drachman, using Curare pipetted into the chorio-allantoic vein, produced an ankylosis in multiple joints of the chick. He observed that "joint differentiation proceeds to a considerable extent in the absence of movement, but articular cavity formation and fine sculpturing of the cartilagenous surfaces require the mechanical action normally provided by

the embryo's own skeletal muscle". He noted that no additional cartilage formed in these articulations but rather the embryonic mesenchyme calcified causing ankylosis in the longer curarized animals.

In the young growing animals in this experiment, the fact that a proliferating cartilagenous cap appeared, shows the importance of mechanical function in joint formation and cavitation. The young connective tissue found in repair areas after condylectomy in young animals evidently still retains a potential to differentiate into cartilage.

Following in order, the older animals do not have this regenerative capability. Instead of the differentiation and growth of cartilage from the connective tissue, the condylar stump rounds off and fibrous tissue fills the condylar defect. Further evidence of a lack of regrowth is elicited in the dentition. While no young animal lost even a deciduous tooth from the added occlusal trauma, the older animal lost a permanent premolar and molar. A wide band of connective tissue remains in the condylar defect.

Two previous histologic studies involving condylectomies in the Macaca monkey have been reported. Sarnat ( 1957 ) reported a fibrous band attached to the condylar stump in an adult animal. Guccione ( 1965 ) reported a normal histologic picture in six young operated animals after post operative periods of four, six, and eight months.

## SUMMARY AND CONCLUSIONS

Condylectomies were performed on young Macaca monkeys with post operative periods ranging from two and one-half weeks to eighteen months. A list of animals and vital statistics are found in Chart I. Records following surgery and sacrifice included gross dissection, radiographic analysis and histologic sections.

In summary a reformation of a functional condyle in the original articular fossa was observed radiographically in all young animals. Two and one-half weeks post operatively one young animal developed a functional condyle with a cap of proliferating cartilage. An adult animal did not form a condyle but was able to masticate with the final condylar stump.

A vertical thickening and arching of the zygomatic arch was observed on the side of condylectomy in all animals.

Medial displacement of the zygomatic arch was seen only on the operated side of unilateral condylectomies. Bilateral operated animals maintained a broad flaring of the temporal base of the zygomatic arch as would normally be seen in control animals.

Deviation of the mandible occurred in all animals dependent on which side the condyle was removed or, in bilateral operated animals to either side.

From this research project the following extrapolation can be concluded:

- ( 1 ) Condylectomy markedly retards the normal increment of mandibular growth in young animals .
- ( 2 ) Condylectomy induces bone changes in the cranium, especially the zygomatic arch and suparticular area .
- ( 3 ) Young animals posess a greater potential for reconstruction of a new articulating condyle after loss of bone continuity in condylectomy .

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APPROVAL SHEET

The thesis submitted by Dr. Dean F. Skuble has been read and approved by three members of the Department of Oral Biology.

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

5/21/68

Date

Nicholas C. Chalkas

Advisor